Residual Life Assessment of Composites with and without Damage

Alan Abraham, Dalbir Singh

Abstract—Composites have become an integral part of many engineering designs beginning with aircrafts to the current day ‘smart structure’ concept, where the structure or component takes an active part in the performance. The development of composites beginning with metal matrix to fiber reinforced plastics has come a long way and now it is possible to tailor a composite to suit a performance criterion. The present study focuses attention on damage effects in composites and finding the residual life and performance assessment. It is centered on study of the stress field developed in the coupon under the application of the tensile loading. Experimental tests were conducted on composite coupons with and without damage so that both stiffness and material modeling are possible to reflect the current status of the composite component. The composite laminate is made up with zero degree unidirectional carbon fibre and cracks were introduced in different angles and tests were conducted. This study helps to find out the decrement of tensile strength of coupons with damages when compared to a virgin coupon.

Keywords—Carbon composites, damage, experimental tests, life time assessment, smart structure

I. INTRODUCTION

The term composite is used to describe two or more materials that are combined to form a structure that is much stronger than the individual components. The simplest composite is composed of two elements; a matrix that serves as a bonding substance, and a reinforcing material. One of the phases is usually discontinuous, stiffer and stronger is called the reinforcement, where as the less stiff and weaker phase is continuous and is called matrix. The greatest advantage of using carbon composite is the high strength to weight ratio. Composites may be designed to be very flexible resisting vibrations, thus eliminating the problem of stress fatigue found in metal structures. Carbon fibers used in this study are unidirectional fibers which are well known for their good tensile strength.

A composite material is a combination of two or more materials in right proportions to get a single entity and improved qualities from the single material. Fiber reinforcement composite materials (FRP’s) are finding increased applications in aircrafts, spacecrafts, automobile fields and electronic industries, since it has high strength to weight ratio and stiffness. Advanced composites are composite materials which are commonly used in the aerospace industries now days. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminum. Advanced composites or smart materials have evolved as a result of combining developments in chemical bonding formulas with new or existing forms of solid structural materials to form the high strength light weight components used structurally in aircrafts.

Akira Kuraishi, Stephen. W and Julie Wang [1] found that during tensile tests, the specimen will fails from the weakest link. This weakest link is unpredictable without testing. This link can be located anywhere in the specimen. In this study tensile strength of unidirectional carbon composite is discussed. Residual life assessment of coupons with and without damage is discussing here. Coupons are provided with different types of minute damages (cracks), namely, vertical crack, inclined crack and horizontal crack. Tensile test is conducted on coupons having these kinds of damages and compared the tensile modulus with a virgin coupon in order to find the decrement in strength when there is damage on coupons. Jane Maria, Sergio Mayer and Cerqueira Rezende [2] studied that tensile loading the woven arrangements tend to alignment with the effort direction. This is due to the micro cracks or damages occur in the polymeric matrix of the composite.

An aircraft and aerospace vehicles during its service life subjected to severe structural and aerodynamic loads, which may caused due to repeated landings and take-off, maneuvering, ground handling and environmental degradation such as stress corrosion. These loads can cause damage or weakening of the structure: especially for an aging aircraft thereby affecting its load carrying capabilities and safe life. This study

II. MATERIALS, EQUIPMENT AND EXPERIMENTAL PROCEDURE

A. Materials and preparation of test coupons

Unidirectional carbon fiber-reinforced epoxy was studied in this paper. Here composite laminate is made up with five plies of reinforcement with epoxy resin were fabricated. A standard ASTM thickness of 3.5mm is maintained throughout. Unidirectional tensile coupons were cut according to the fiber direction, zero degree orientation. The fiber volume fraction of the composites was 60%. Compression molding
technique is used here for the fabrication of coupons. Compression molding is a manufacturing process that uses a male and female mold. Using hand layup method carbon fiber and epoxy resin is filled in female mold. After that it is compressed with male mold under standard pressure. Curing time for this method is 48 hours. Then coupon is cut by water jet cutting in required dimension (ASTM D3039). Coupon has dimension of length 250mm, width 15mm and thickness 3.5mm. Fig. 1 shows the geometry of the coupon. Fig. 2 shows the prepared typical test sample for the tensile tests.

![Fig. 1: Geometry of coupon (ASTM D 3039)](image)

B. Generation of crack

After coupon is cut according to above mentioned dimension crack has made on it. Crack is generated with a drill bit of 800 microns with vertical milling machine. Damage (Crack) has a dimension of 4mm length, 800 microns of thickness and 1mm of depth. Fig. 3 shows the crack or damage formation on coupon with the help of vertical milling machine.

![Fig. 3 Making damage on test coupon with vertical milling machine.](image)

A typical damage (crack) made over the surface of coupon is shown in fig. 4.

![Fig. 4: Crack on coupon](image)

C. Testing machine

Testing machine used here for tensile test is Universal Testing Machine or widely called as UTM machine. FIE make UTN 40 model UTM machine is used here. Maximum capacity of this particular UTM machine is 50 tones. Here strain rate is maintained as per ASTM standard.
III. RESULTS AND DISCUSSION

In this study, tensile test is carried out on unidirectional carbon laminate having damage or crack on it. Results obtained from these tests are compared with the tensile test result of a virgin coupon. Results obtained from virgin coupon, coupon with vertical, inclined and horizontal crack is given in Table 1. It is found that lives of coupons are considerably decreasing when a crack is imposed on it. Results shows that virgin coupon possesses maximum value for Fmax, ultimate tensile strength and tensile modulus. The order of decrement of residual life is given in fig.6.

A. Comparison of Mechanical Properties.

In Table 1 comparison of mechanical properties are given. Mechanical properties like ultimate tensile strength, tensile modulus and ultimate breaking load are compared here. In this study, it is found that coupon which having horizontal damage possess less residual life when compared to other damaged specimens. Vertical damaged coupon have the highest residual life against other two damaged specimen.

**TABLE 1 COMPARISON OF MECHANICAL PROPERTIES**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No Crack</th>
<th>Vertical Crack</th>
<th>Inclined Crack</th>
<th>Horizontal Crack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fmax</td>
<td>24.81 KN</td>
<td>21.56 KN</td>
<td>16.44 KN</td>
<td>14.84 KN</td>
</tr>
<tr>
<td>UTS</td>
<td>413.49 MPa</td>
<td>359.40 MPa</td>
<td>316.12 MPa</td>
<td>247.29 MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>12.8 GPa</td>
<td>11.2 GPa</td>
<td>10 GPa</td>
<td>9.2 GPa</td>
</tr>
</tbody>
</table>

B. Stress-Strain Relation

Fig 5 shows the stress-strain relation of damaged coupons against virgin coupon. Virgin coupon shows highest stress value and coupon with horizontal damage shows least value.

C. Comparison of Residual Life Strength

Fig 6 shows the percentage decrement of strength of each coupon with and without damage. When compared to virgin coupon, residual life of horizontal damaged coupon is decreased by 28.12%. Coupon with inclined and vertical damage strength is decreased by 21.8% and 12.5% respectively.

The Fig 7 shows the picture of failed coupons.

IV. CONCLUSION

Based on the experimental observations and discussions following conclusions can be drawn:

From the experiment results conducted on the UTM under controlled environmental conditions, it is comprehend that the horizontal induced crack is the dominating factor above all the other induced crack in the coupons. It is observed that stiffness is the highest in the virgin coupons. Hence while predicting the remaining life of the composites during service under different loading and environmental conditions if the crack is of horizontal nature that is in perpendicular to the fiber loading directions can lead to the catastrophic failure in the aerospace vehicles.

Also we have seen from the bar diagram that inclined induced crack is next dominating factor in predicting the remaining life assessment of the composite lamina. So we can conclude that the remaining life of damaged carbon fiber unidirectional composite coupons will be less if the crack is perpendicular to the loading direction.
Damages in a vertical manner have considerably less effect when compared to inclined and horizontal damages. In other words, if the crack or damage is parallel to the fiber orientation, then the chance of catastrophic failure is less.

REFERENCES


